Modification and Reconstruction of Seismographs and Analysis of the Structure of Seismographs and the Local Seismic Activity in Southeastern Wisconsin

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Abstract

This project began with the reassembly of the Carthage College seismometers and enhancing them to be more sensitive than they have been in the past. The potential seismic activity is collected as an electrical signal and modified through calculations in the lab in an effort to find repeated patterns and modes that may have a correlation to non-tectonic events, such as, but not limited to, motions of Lake Michigan or HVAC operations in the building the apparatus is stored in.

Contents

1 Introduction

Seismology is the measuring of the earth moving below our feet. Under the ground, there are plates of land that shift with the movement of the core of the earth. These are called tectonic plates and their collisions with each other lead to hills, valleys, and mountain tops. Professionals study the movement of tectonic motion and the resulting ground waves in order to predict and determine the consequences on the surface [1]. The types of waves and their motions will be described in the following sections.

In the Midwest, there is very little tectonic activity of any current importance since there are no edges to a plate in the area so the only detected action is from the entire plate moving. Some places in Illinois have small-amplitude earthquakes around two or three times a month.

This project was previously developed and managed by Charles Staniger (graduated Carthage College 2007) who built the basic seismograph and originally created the circuit board to collect the data. He started the project in Carthage's Summer Undergraduate Research Experience and progressed into his senior year to complete the requirements for his thesis and graduation [2]. Dr. Doug Arion passed the project onto myself providing an opportunity to receive research credit.

2 Seismology Background

When plates shift, the ground contracts and creates a compression wave, much like a sound wave, that travels through the ground until it becomes dissipated in the area around it, much like the ripples of water. These are called P waves, for Primary, and are the first, immediate note of an earthquake. See Fig. 1.

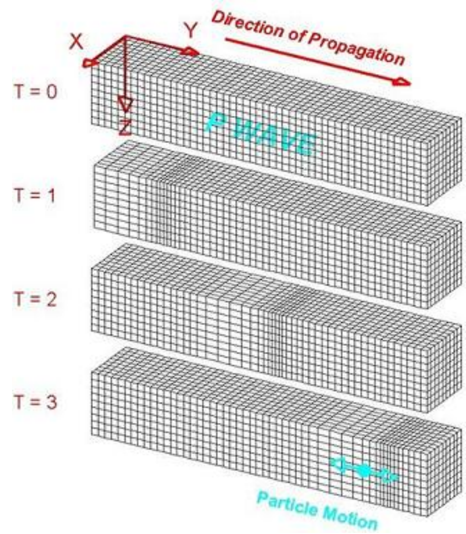

Figure 1: P-wave movement

Secondly (for S waves), there is a ripple in the ground similar to a wave in the ocean that is the result of the plate moving up and down. Both of these waves are called body waves and can travel through the earth. See Fig. 2.

Also, the detection area experiences two types of ground waves. The first is called a Love wave and is the result of the earth moving from side-to-side in relation to the propagation of the wave itself. The second wave is called Rayleigh waves and shows the earth rolling under its surface, much like a strong wave in the ocean forming into a tidal wave. See Fig. 3. These two ground waves are the cause for most of the damage seen in earthquakes [1].

Seismographs are used to measure the intensity and time between the various waves. P-waves travel consistently faster than S-waves and the time between the two can be used to determine the distance from the epicenter (the origin of the earthquake) to wherever it is detected. When three or more stations receive data from seismic activity, the stations can use the distance from their center to triangulate the original center of seismic action.

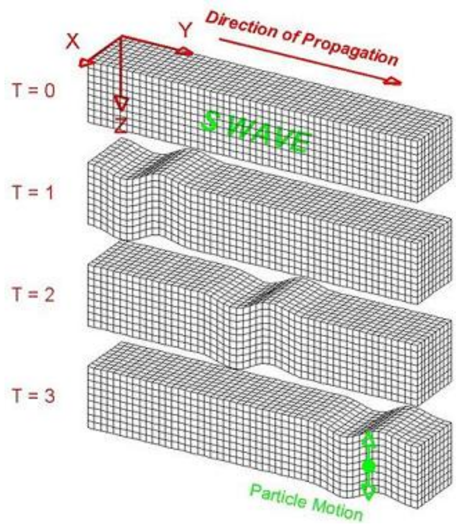

Figure 2: S-wave movement

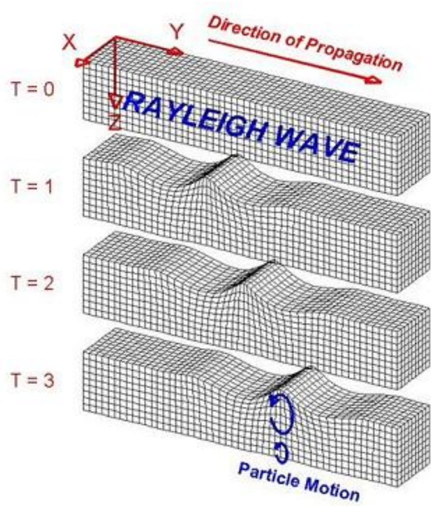

Figure 3: Rayleigh movement

3 Seismography Background

The basic seismograph measures the earth's movement with a pendulum that is hung in free-space such that the earth can move and the pendulum stays motionless. Very basically, this can be thought of as a vertical pendulum that has a pencil at the base of the weight that draws a line on a sheet of paper. This reflects the motion of the ground and progression of the waves in through the area as the pencil/pendulum stay straight.

This projects specific type of seismograph (called Lehman seismographs) have a magnet surrounding a coil of wire at the end of a horizontal boom. The magnet remains fixed hanging in free-space while the coil of wire moves with the ground. This induces a voltage across the wire that can be connected into a computer and monitored. A Lehman seismograph is shown in Fig. 4 [4].

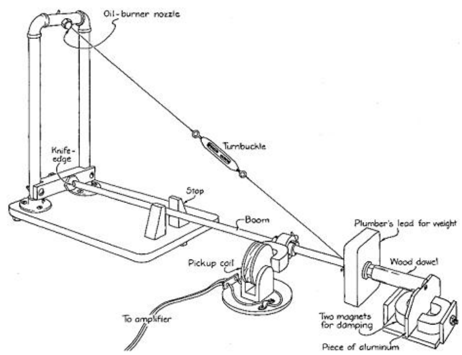

Figure 4: Basic model of Lehman Seismograph

Creating a useful measurement of the seismic activity was popularized by Dr. Charles Richter. Richter focused on creating a scale of the intensity of earthquakes that we simply call the Richter Scale. He based the scale from one to ten, where each step is ten times stronger than the one lesser. Over several years, Richter devised Equation 1 to fit the data that calculates the magnitude of the earthquake depending on the amplitude (A) in millimeters (where one millimeter in height is one second of time) and the seconds between the primary and secondary waves (Δt) [3].

$$M = Log(A) + 3Log(8\Delta t) - 2.92 \tag{1}$$

In the general case, the primary wave travels 1.7 times faster than the secondary waves. Exactly locating the epicenter of earthquakes is as important as knowing how strong it is, and depends on the knowledge of the velocity of each of the primary (P_v) and secondary (S_v) waves and the time between the two waves (P_t and S_t, respectfully) striking the area. Since the time difference is always relative to the distance to the epicenter, we start by assuming

$$P_t = \frac{d}{P_v}$$

$$S_t = \frac{d}{S_v}.$$

Although the time from the earthquake to detection is unknown, a difference relation between the two can be made.

$$P_t - S_t = d(\frac{1}{P_v} - \frac{1}{S_v})$$

From this, we solve for the distance and get the final result in equation 2.

$$d = \frac{P_t - S_t}{\frac{1}{P_v} - \frac{1}{S_v}} \quad (2)$$

Once the distance is known to the epicenter, three different detection sites can cooperate and determine the actual location of the epicenter. Each of the three locations knows the distance from the seismograph and the epicenter, and if drawn on a map, two circles will intersect at two points, but three can only intersect at one point. When the epicenter of the earthquake is known, it becomes possible to determine the potential damage to the area and creates a method of analysis for the tectonic plates in the area. Eventually, a prediction could be made of earthquakes in any area and prevent too much damage or any at all.

4 The Project

Seismographs work on the simple principle that the earth moves a detector and a pendulum hangs still in space. Conversely, to the coil, the pendulum moves relative to the movements of the earth. With the seismographs previously built by Staniger, there are magnets on the end of the pendulum that move around a coil of wire. The result of the earth's movements are converted into voltage by Faraday's Law of Magnetic Induction.

The seismographs that were previously built did not last much past Staniger's graduation. As such, the apparatus was partially damaged and the computer that managed the information was destroyed. In an effort to repair the seismograph back into working condition, the opportunity was used to make changes, specifically stronger magnets on the pendulum. The overall structure of the seismograph need not be changed, so the modifications do not take away from the abilities of the original setup.

Let it be defined that the x-axis is in the direction of the boom, horizontal to the ground, y-axis is horizontal to the ground perpendicular to the boom and the z-axis is the direction in the vertical as shown in figure 5.

The earth's gravity creates the tendency of the pendulum to return to rest and the length determines the natural period. If at any point the earth movement is slower than the natural period, then the movement will not be detected. The natural period of any pendulum can be determined from length (l) in meters and the angle off the x-axis (θ) in the -z direction in Equation 3.

$$P = 2\pi\sqrt{\frac{l}{g * sin(\theta)}} \quad (3)$$

The length of the boom provided from Staniger's project is one meter, so we look to see the available angles with a one meter boom. Figure 6 shows the period of a one meter boom at any given angle. This shows that the optimal angle of the pendulum is near zero from the

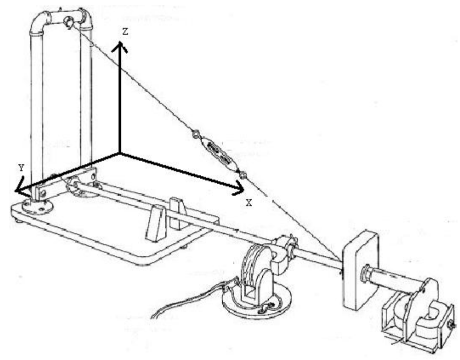

Figure 5: Axis of pendulum

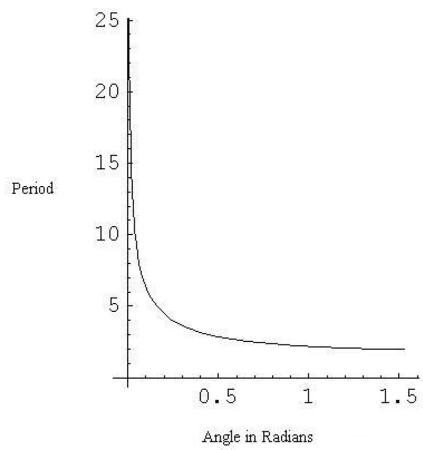

Figure 6: Period vs. angle

x-axis.

If we let the boom to be perfectly horizontal, then we note that the period is infinite. With an infinite period, the seismograph would detect anything that made the ground move. But from basic engineering constraints, it is impractical to build something that has a detector in only one direction from the boom. Once the boom moves away, there is little likelihood of the boom returning to a detectable area near the coil.

As such, there must be some angle to have the pendulum return back to natural position. We would like the boom to be as horizontal as possible, but even if it is barely angled, it may prove too difficult to steady in the first place. As seen from figure 6, there is some room to work with to keep the natural period high, and still have some angle away from the horizontal. Conveniently, the natural period of a boom one meter in length is at least two seconds. We already know that most earthquake have a period of one second, so a vertical pendulum is allowed for this project. Staniger build the project to have a period of approximately 10 seconds, which implies an angle of approximately 2.5 degrees from the x-axis in the -z direction.

With the pendulum, there must be some form of dampening, else the pendulum will swing back and forth indefinitely. Staniger modified the apparatus so that a paddle hangs from the boom into a shallow pail of oil. Oil is a great method of dampening, since the liquid does not transfer energy into the pendulum, and anything thicker would have dragged the pendulum with the base.

To begin collecting data, voltage is generated from the moving magnet. Faraday's Law of Magnetic Induction can be used to determine the voltage from the signal. Faraday's law claims that the force induced ($\vec{F}$) depends on a charge (q) moving with velocity of ($\vec{v}$) in a magnetic field ($\vec{B}$) represented in equation 4.

$$\vec{F} = q(\vec{v} \times \vec{B}) \tag{4}$$

Any energy can be represented as a force times distance, so we bring in the distance vector ($\vec{d}$) to equation 4 to get equation 5.

$$E = \vec{d} \cdot q(\vec{v} \times \vec{B}) \tag{5}$$

Since the seismograph is set up so that the magnetic field and velocity vector are perpendicular, we simply multiply the amplitudes of the vectors together.

$$E = dqvB$$

Since we are looking for the voltage, we divide out the charge and solve for each individual voltage.

$$V_i = \frac{E}{q} = dvB$$

Finally, this is for each N coils in the wire (in this specific case, Staniger constructed the coils with 19,000 turns), therefore, we know we will induce N electrons in the wire. The resulting equation 6 is the total voltage created when the magnets move.

$$V = NV_i = NdvB \tag{6}$$

When the original magnets was installed, it had a magnetic field around 20 Gauss. The new magnets have approximately 250 Gauss. This implies that the improved sensitivity of the seismograph will generate over 10 times the voltage than before.

We already know that the rate of displacement in a P-wave is approximately 1 Hertz [7]. Also, a typical 1.0 (Richter Scale) earthquake has a total ground displacement of 2.3 nanometers if the detector was 210 meters (about a tenth of a mile) from the epicenter [8]. Therefore, we can solve for the expected voltage.

$$V = (19,000)(2.3 \times 10^{-9})(1)(250)$$

$$V \approx .011 Volts$$

What we will see shortly is any voltage above a couple millivolts is detectable because of the amplification in the circuitry. This gives us some idea that the seismographs can detect very small movements in the ground.

5 Electronics

Like most simple circuits, the electronic composition is made from the input coil, an amplifier, filter and power supply to increase the output voltage and filter our frequencies not made from seismic activity. To manage the data processing, the final output goes into LabVIEW to be copied into an graphing file and analyzed. Finally, LabVIEW will publish the output on the web for public viewing.

The amount of voltage created by the moving magnets is on the order of a couple millivolts. Unfortunately, a lot of noise can drown out that signal and the output would be negligible. To be useful, the output should be amplified to whole volts. As such, a Max420CPA operational amplifier is made to amplify any signal that will be combined through a low-pass filter. With the circuit provided, the amplification should be on the order of 1,000 times through a feedback resistor of 10MΩ. This means that the previous hypothetical voltage to be read will be approximately 2 volts. This chip will also filter out common noise found in power lines and wall outlets. With a 0.01 μF capacitor in parallel with the feedback resistor, all of the 60 Hz noise will be eliminated [10].

With the natural period of the pendulum being approximately 2 Hz and most earthquakes shake around 1 Hz, there must be a filter to block out any noise that would be too high to be relevant. Since most of this noise has a vibrational period less than one second, a TL-082 JFET operational amplifier is used to have sharp cutoffs [10]. The only frequencies allowed through the filter are those below 5 Hz.

The power supply on the original circuit was made to take power from a transformer plugged into the wall and convert it into direct current to power the chips. It was made to have a final output of ±12 volts. Unfortunately, there was some fault in the circuit board and the power had to be supplied from an external power supply provided from the physics department.

6 Seismological Analysis

The output data from the seismograph is processed through LabVIEW, a computer program that is common for electronic data processing and simulations of electronic equipment. LabVIEW stands for Laboratory Virtual Instrument Workbench and is made to create programs through user texts. It is made for engineers who have many tasks to be managed at once and cuts down on processing time for analyzing data and presenting results [11].

Since LabVIEW is made for professional use, there is a tutorial made for non-professional users. One of the templates available shows how to have an input signal and save it to a file on the computer. It can easily include a graphic output that shows what is happening on the seismometer since it simply acts as a oscilloscope and shows the voltage. To hook the circuit into LabVIEW, a data acquisition unit (DAQ) plugs from the output of the seismograph into the computer through a USB port. To save any data received from the seismograph, LabVIEW needs to use a feature that exports the data into a text file that can be opened in Microsoft Excel. From there, a graph is made from the data to recreate the actual movement of the earth [2].

Meanwhile, LabVIEW publishes the signal sent through the DAQ onto the web. The software comes with a feature to output the data onto a website managed strictly by the computer feeding the information. To publish the data, Carthage College needs to lower their Internet security to allow the user free reign to make the information available. The website will be made public at a later time.

7 Discussion

As a recap, there are three types of seismic waves, modifications to the previous seismographs, and data processing.

Three different types of waves are created from the tectonic plates moving around the earth: P-waves, S-waves, and Rayleigh waves. Knowing how long it takes between the P-waves and S-waves to reach the seismograph allows calculations to the distance of the epicenter. With other research sites, the location of the epicenter can be found.

The seismographs have the ability to measure the seismic activity in the area and provide more than ten times the output voltage than before. From this, more accurate data can be processed while still maintaining the filtered circuit to prevent external activity. Currently, only test data has been collected for analysis. This means that further testing needs to happen to in order to find periodic motion of the lake. Fortunately, the previous data had regular pulses of signal that no longer appear in the output data.

There is a lot of possible work to be done on this project. In the coming years, many other undergraduates can expand on the technology currently in use. For example, a second seismograph could be finished in similar fashion so that the exact velocity of the ground waves could be calculated when every motion is detected. Also, the circuit can be modified for greater amplification. Finally, an automatic computational process can be programmed into LabVIEW so that the seismograph can ignore certain data that seems out of place.

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